Adapting to Climate Variability, Thresholds, and Extremes in the Southwest: The Climate Assessment for the Southwest (CLIMAS)

Annual Progress Report

May 1, 2013 through May 31, 2014

2013-14 CLIMAS Team

Principle Investigators: Jonathan Overpeck (Lead PI), Bonnie Colby, Andrew Comrie, Michael Crimmins, David DuBois, Daniel Ferguson, George Frisvold, Gregg Garfin, Margaret Wilder, Connie Woodhouse

Staff Researchers: Zack Guido, Gigi Owen, Ryan Thomas, Jessica Dollin, Anna Masayesva, Jaimie Galayda

Post Doctoral Researchers: Heidi Brown, Cory Morin, Adrian Quijada-Mascareñas, Jeremy Weiss

Graduate Students: Rebecca Armenta, Ting Bai, Becky Brice, Mindy Butterworth, Jessica Conroy, John Flaherty, Christina Greene, Mia Hammersley, Ron Klawitter, Emma Lawlor, Tatiana Marquez, Jonathan McLeod, Georgia Pfeiffer, Cody Routson, Yizhi Zhou

Research Affiliates: Julie Brugger, Katharine Jacobs, Diana Liverman, Alison Meadow, Kiyomi Morino

Climate & Society Fellows: Chris Guiterman, Ling-Yee Huang, Rebecca Lybrand, Sarah Truebe

New Areas of Focus & Partnerships in 2013-14

Southwest Climate Podcasts

CLIMAS Investigators: Zack Guido, Michael Crimmins, Ryan Thomas, and Jessica Dollin

El Niño, the monsoon, increasing temperatures, and dwindling reservoir storage are just a few of the climate-related issues that periodically punctuate the news cycle in the Southwest. CLIMAS scientists discuss these issues in monthly climate podcasts and special podcast series. The podcasts synthesize information from disparate sources, translating the national and global discussions for the Southwest. The podcasts also bring in the latest climate science, covering climate-related topics with nuance but not shrouded in technical jargon.

There is little media that focuses on synthesizing and adding value to climate events and science in real time. These podcasts represent a novel way of informing the Southwest about current and future conditions. It is also another avenue in which CLIMAS can maintain routine contact with our stakeholders and the media. Information presented in the podcasts has been used in other media forms, such as radio and print.

Climate & Society Graduate Fellows Program

CLIMAS Investigators: Gigi Owen, Daniel Ferguson, Zack Guido, Ryan Thomas, Rebecca Lybrand, Ling-Yee Huang, Chris Guiterman, Sarah Truebe

The Climate & Society Graduate Fellows Program provides support for currently enrolled University of Arizona graduate students from any degree-granting program whose work is focused on the nexus of climate research and decision making. Up to four fellowships in the amount of $5,000 each are awarded annually, leveraged with funds from the Office of the Vice President for Research at the University of Arizona.

Current 2014 Fellows will present results from their research projects, described below, at a CLIMAS-sponsored symposium in November 2014.

- *Rebecca Lybrand* is creating two short soils films that integrate results from her dissertation on how soil carbon cycling changes with shifting climates in the Southwest. Surveys will be used to evaluate the effectiveness of two different types of communication techniques used in these videos.

- *Ling-Yee Huang* is developing an integrated climate science and climate law curriculum for the James E. Rogers College of Law at the University of Arizona. The goal is to expose law students to the process and methods of climate science and climate change litigation that relies on this information.

- *Chris Guiterman* is working with Navajo Forestry Department foresters to quantify the climatic drivers of forest growth in the Chuska Mountains, in New Mexico. The study will provide an improved assessment of forest response to climate change that is vital to natural resource planning and management.

- *Sarah Truebe* is working with scientists and cave managers to develop current "best practice" guidelines for sampling speleothems, which are archives of paleoclimate information. The final output will be a peer-reviewed methodology assessment, giving

managers and scientists options for sampling speleothems in a more conservation-friendly way.

Disentangling the Influence of Antecedent Temperature and Soil Moisture on Colorado River Water Resources

CLIMAS Investigators: Connie Woodhouse and Becky Brice

Research Partners: U.S. Geological Survey - Bozeman, MT and Denver, CO; Alaska Climate Science Center; Desert Research Institute; University of Nevada - Department of Geography

This is a DOI Southwest Climate Science Center project, with leverage from CLIMAS. The main goal of this project is to better understand how the set of hydroclimatic factors - prior summer/fall soil moisture, cool season precipitation/snowpack, and late winter/spring temperatures - contribute to low annual flows on the Colorado River. We will use a combination of instrumental data, tree-ring reconstructions, and downscaled CMIP5 projections to investigate the differing roles of these factors in both instrumental period droughts and droughts that have occurred over past centuries, including conditions in major sub-basins. We will test the sensitivity of annual low flows to different CMIP5 scenarios of changes in soil moisture, winter precipitation, and winter/spring temperatures, and compare climate conditions associated with historic/paleo low flows to those associated with low flows derived from downscaled projections.

This understanding is critically important to resource managers who are currently anticipating the impacts of climate variability and change on limited water supplies in the upper Colorado River basin. To develop the proposal, we engaged with a group of Colorado River basin water managers who assisted in directing research questions and ensuring the project's relevance to resource management. This group of water managers will form an advisory board to guide the analysis and generation of research products through interaction with the science team, an interdisciplinary group with expertise in climatology, paleoclimatology, hydrologic modeling, and climate projection analysis, with extensive experience working with resource managers. Additional partnerships with Western Water Assessment (WWA) and CLIMAS will promote a broader exposure to and use of project results by water resource management through a workshop for resource managers and articles featured in WWA and CLIMAS online publications for stakeholders.

Fostering Conducive Conditions for Climate Assessments: Collaborative Scenario Planning and the Colorado River Basin Study

CLIMAS Investigators: Gregg Garfin and Mia Hammersley

The Colorado River Basin Supply and Demand Study, conducted by the Bureau of Reclamation, was an unprecedented attempt to bring together a variety of experts and stakeholders from the watershed to address the current imbalance between supply and demand from 2012 through 2060. The Basin Study was also the largest scenario-planning project to ever be conducted by the Bureau of Reclamation. While most scenarios are either an expert (or "judgment driven") scenario model or a stakeholder-defined scenario, the Basin Study incorporated aspects from both of these models, creating a collaborative model. We hypothesize that this collaborative

scenario planning process made it easier for stakeholders to find common ground on pathways to address common challenges, and that it fostered the use of climate change information in decision making. This project aims to evaluate the aforementioned hypotheses, through a critical evaluation of the Basin Study Scenario Planning activity and Basin Study participant responses to interview questions.

Developing and Leading a Climate and Health Research Network on the University of Arizona Campus

CLIMAS Investigators: Margaret Wilder, Heidi Brown, Jonathan Overpeck, Daniel Ferguson, and Emma Lawlor

During 2013-14, Wilder and Brown initiated a climate-health research nexus for interdisciplinary research on these topics at the UA. A workshop convened on February 14, 2014 attracted about 40 researchers, including representation from the Colleges of Social and Behavioral Sciences and Public Health, with some representation from the physical sciences. Representatives from the Arizona Department of Health Services CDC-funded BRACE Program (on heat impacts on public health) were present and expressed interest in participating with the UA research community. The goals of this initiative are to: 1) foster a community of interdisciplinary researchers working at the intersection of climate and health; and 2) develop core concepts for fruitful collaboration on externally funded grant proposals. At the end of the workshop, a steering committee was formed to plan next steps and convene a subsequent meeting of the full group. By May 2014, the steering committee met several times and refined its plans for a future meeting in fall 2014.

Selected Research Findings from 2013-14

Adaptation to Climate Variability and Change: Markets, Policy, Technology, and Information

Lead CLIMAS Investigator: George Frisvold

- No single institutional source of irrigation information was relied upon by more than half of irrigators in Arizona and New Mexico. A significant share of irrigators did not rely on public sources of irrigation information (university/extension specialists or government specialists), while irrigation districts often play a central role in scheduling and information provision, especially for small farms. Public agencies might fruitfully target irrigation district staff for their information services, acting as 'wholesalers' of information to the districts, which in turn interact with irrigators directly.
- While several commentators have suggested adoption of improved irrigation will be important for agricultural adaptation to climate change in the Western US, regression results suggest that smaller scale producers adopt more efficient sprinkler irrigation systems to a significantly lower extent than their larger-scale counterparts. Even among larger operations, adoption of sprinkler irrigation may not be a preferred adaptation to climate warming. Sprinkler adoption declined in Spring/Summer temperature and growing-season-adjusted Fall/Winter temperature. Results suggest sprinkler irrigation is a more likely climate change adaptation in areas that are relatively cold and where extreme precipitation events increase.

Air Quality and Climate

Lead CLIMAS Investigator: David DuBois

- Regional fire incidents may trigger high ozone episodes, which may exceed air quality standards.
- Hospital emergency room (ER) and admissions data indicated effects of PM10, PM2.5 and ozone on ER visits during the April to September period are impacted by windblown dust and wildfires. Increased cardiovascular ER visits were estimated for PM10 (3.1%) and PM10-2.5 (2.8%) for all adults during this period. Sources within 500km of the study area accounted for most of the particle mass and ozone concentrations.

Tribal Drought Information for Monitoring, Assessment, and Planning (Tribal DrI-MAP)

Lead CLIMAS Investigator: Michael Crimmins

- Indices that capture regional hydroclimatic extremes (e.g. dry spell length and number of rain days) lend unique and important insight into the multiple pathways that drought conditions can develop. This insight can inform more locally relevant drought monitoring techniques.

National Climate Assessment

Lead CLIMAS Investigator: Gregg Garfin

- Increased warming, drought, and insect outbreaks, all caused by or linked to climate change, have increased wildfires and impacts to people and ecosystems in the Southwest. Fire models project more wildfire and increased risks to communities across extensive areas.
- Projected regional temperature increases, combined with the way cities amplify heat, will pose increased threats and costs to public health in Southwestern cities, which are home to more than 90 percent of the region's population. Disruptions to urban electricity and water supplies will exacerbate these health problems.

Adaptation Strategies for Water and Energy Sectors in the Southwest

Lead CLIMAS Investigator: Bonnie Colby

- More flexible water trading arrangements across water users within watersheds can substantially reduce the economic impact of drought.
- Electric utilities need to consider the best ways to meet higher peak loads for cooling during the summer months in the Southwest, under climate change.

Sectoral Impacts of Drought and Climate Change

Lead CLIMAS Investigator: George Frisvold

- Project analysis used an integrated, dynamic biological-economic model to evaluate strategies to control invasive buffelgrass in the Sonoran Desert recommended by the multi-agency (federal, state and local) Buffelgrass Strategic Plan. A warmer southwest climate would expand the range of this invasive plant.
- Two strategies—potential damage weighting and consecutive year treatment—used in combination, provided significant improvements in long-term control over no control and over a strategy of minimizing current damages in each year. Without treatment, potential damage increases exponentially with buffelgrass growth.

Water Needs and Impacts of Climate Change and Water Diversion on Ecosystems of the Upper Gila River in New Mexico

Lead CLIMAS Investigator: Gregg Garfin

- The projected five-model weighted average streamflow for the Gila River at Gila is a 6% decrease in water quantity (with a 15% decrease in the median streamflow); for the Gila at Virden it is an 8% decrease (15% median decrease), and for the San Francisco River at Clifton it is an 11% decrease (19% median decrease) for the time period 2041-2070 in comparison to the time period 1971-2000.

- Low flows are projected to decrease (get even lower) in the future, and very high flows are expected to increase (get even higher), even as overall streamflow is projected to decrease.

Managing Demand, Rethinking Supply: Adaptation, Conservation, and Planning in the Drought-prone Southwestern U.S. and Northwest Mexico

Lead CLIMAS Investigator: Margaret Wilder

- In the City of Tucson, citizens' water advisory boards can increase the institutional adaptive capacity of a local water utility. Although the advisory boards do not specifically address climate change, they advise elected officials on matters pertaining to water resources adaptation. Indicators of adaptive capacity such as fair governance, legitimacy, and social learning were, generally speaking, enhanced by the Citizens' Water Advisory Council's existence, while other relevant aspects of water governance (e.g., conflicting goals, politics) were not adequately captured by the adaptive capacity analysis.

Climate Change Mitigation Strategies and Policies

Lead CLIMAS Investigator: George Frisvold

- Contrary to assertions often made, reliance on solar thermal technologies to meet western state Renewable Portfolio Standards for electricity generation will not impose a significant burden on water supplies.

Key Publications in 2013-14

Ault, T., J. Cole, J. Overpeck, G. Pederson, and D. Meko. 2013. Assessing the risk of persistent drought using climate model simulations and paleoclimate data. *Journal of Climate* (In press). http://dx.doi.org/10.1175/JCLI-D-12-00282.1

This paper suggests an entirely new paradigm for understanding drought risk. Future risk of multi-decadal "megadrought," like the type seen in the recent paleoclimate record, is substantially higher than previously thought. Moreover, state-of-the-art climate models (e.g., CMIP5) significantly underestimate this risk.

Brugger, J. and M. Crimmins. 2013. The art of adaptation: Living with climate change in the rural American Southwest. *Global Environmental Change* 23(6): 1830-1840. http://dx.doi.org/10.1016/j.gloenvcha.2013.07.012

This paper considers how climate change research and policy interprets the concept of adaptation. This paper draws attention to the need for policies and institutions that recognize and support a wide range of locally relevant adaptation strategies.

Garfin, G., G. Franco, H. Blanco, A. Comrie, P. Gonzalez, T. Piechota, R. Smyth, and R. Waskom. 2014. Chapter 20: Southwest. In *Climate Change Impacts in the United States: The Third National Climate Assessment.* Eds. J. Melillo, T. Richmond, and G. Yohe. U.S. Global Change Research Program, 462-486. http://nca2014.globalchange.gov/report/regions/southwest

The 2014 National Climate Assessment shows that climate change is already happening across the United States, and that residents of the Southwest have been affected by changes to fire, forest mortality, and coastal flooding. The Federal government requires a timely and accurate report of climate change and its impacts in the region. Regional decision-makers of the Southwest also need information on climate change and its regional impacts.

Frisvold, G. and K. Konyar. 2013. Climate Change Mitigation Policies: Implications for Agriculture and Water Resources. *Journal of Contemporary Water Research & Education* 151(1): 27-42.

Climate change mitigation policies such as cap and trade with carbon offsets may encourage significant water conservation in some U.S. regions, but increase competition for water in others. By reducing fertilizer use and dramatically altering land use patterns across the Mississippi Basin, it may provide unexpected water quality benefits.

Morin, C. and A. Comrie. 2013. Regional and Seasonal Response of a West Nile Virus Vector to Climate Change. *Proceedings of the National Academy of Sciences (PNAS)* 110(39): 15620-15625. www.pnas.org/cgi/doi/10.1073/pnas.1307135110

The potential impacts of climate change on human health are possibly large and not yet well understood, especially for vector-borne diseases. This paper provides projections of how

climate change may affect the population of a West Nile virus mosquito vector across the southern United States. Results imply that disease-transmission studies and vector-control programs must be targeted locally to maximize their effectiveness.

Rodopoulou, S., M. Chalbot, E. Samoli, D. DuBois, B. San Filippo, and I. Kavouras. 2014. Air pollution and hospital emergency room and admissions for cardiovascular and respiratory diseases in Dona Ana County, New Mexico. *Environmental Research* 129: 39-46. doi: 10.1016/j.envres.2013.12.006

This paper shows significant correlations between ozone, PM10, PM2.5 and emergency room and hospital admissions in Las Cruces, NM.

Vano, J., B. Udall, D. Cayan, J. Overpeck, L. Brekke, T. Das, H. Hartmann, H. Hidalgo, M. Hoerling, G. McCabe, K. Morino, R. Webb, K. Werner, and D. Lettenmaier. 2013. Understanding Uncertainties in Future Colorado River Streamflow. *Bulletin of the American Meteorology Society* 95: 59–78. http://dx.doi.org/10.1175/BAMS-D-12-00228.1

This paper is the product of a cross-RISA project to reconcile previous studies of future Colorado River streamflow change. It provides the best estimates of how streamflow in the Colorado River will be affected by climate change, and how climate change will exacerbate natural drought and megadrought impacts on Colorado River flow. The paper clarifies the no-regrets advantages to careful drought planning.

Selected Outreach Activities in 2013-14

Air Quality and Climate

Lead CLIMAS Investigator: David DuBois

Convened workshops about human health and dust exposure in New Mexico:

1) Dust Summit, City of Las Cruces, NM. February 19, 2014.

   Communicated information about the hazards of dust and ways to mitigate it in suburban areas of Las Cruces. Advised city officials about mitigation and health effects of dust.

2) Two workshops jointly conducted between New Mexico State University and the Environmental Protection Agency Border 2012 New Mexico-Chihuahua Rural Task Force.

   Topics included health effects of particulates, protection from high levels of dust, and potential exposure to valley fever. Columbus, NM and Palomas, Chihuahua, November 2013. Provided materials and presented in both Spanish and English.

Planning for Local Government Climate Challenges: Connecting Research and Practice

Lead CLIMAS Investigator: Daniel Ferguson

Convened two workshops with municipal leaders from Flagstaff and Tucson, AZ:

1) Regional Climate Summit for Municipal Leaders: Economic, Health, Water & Transportation Impacts. Tucson, AZ. November 14, 2013.

   This workshop was planned with a small committee of stakeholders to bring together southern Arizona municipal leaders (e.g., local politicians, upper level municipal management) to explore the risks, potential costs, and proactive solutions necessary to combat and cope with climate change challenges affecting southern Arizona. The planning committee wanted this workshop to help spur action and regional coordination of climate adaptation planning.

2) Flagstaff Climate Adaptation and Resiliency Planning Workshop. Flagstaff, Arizona. October 24–25, 2013.

   To advance climate resiliency planning, the City of Flagstaff partnered with members of the University of Arizona's (UA) Climate Assessment for the Southwest (CLIMAS) and Arizona State University's (ASU) Decision Center for a Desert City (DCDC) and Center for Integrated Solutions to Climate Challenges (The Climate Center) to develop climate resiliency performance measures.

Assessment of Climate Change in the Southwest United States: a Technical Report Prepared for the U.S. National Climate Assessment

Lead CLIMAS Investigator: Gregg Garfin

1) Media coverage after the release of the Southwest Report:

   Liverman, D. and G. Garfin. 2013. A Warning from the American Southwest: It's Getting Hotter. *The Washington Spectator* 39(10): 1-4. (October 1, 2013)

http://www.washingtonspectator.org/index.php/Environment/a-warning-from-the-american-southwest-its-getting-hotter.html#.UmBgmFCsiM5

Falk, D. and G. Garfin. 2013. Guest Column: There's no doubt: Earth is warming, and it's our fault. *Arizona Daily Star.* September 29, 2013.

Garfin, G. 2013. Guest Column: How would an extra month of 100-plus degree days feel? *Arizona Daily Star.* May 1, 2013. http://azstarnet.com/news/opinion/guest-column-how-would-an-extra-month-of--plus/article_54978a1f-dc1f-5ec6-afdd-6e8b3c790c26.html

2) Presentations regarding findings of the Southwest Report and National Climate Assessment:

May 2013:

- Climate Change in the Tucson Region: Sustainable Living or Abandoned Wasteland? Tucson, AZ.

June 2013:

- Science on the Sonoita Plain Symposium. Elgin, AZ.
- NASA/Arizona-Sonora Desert Museum Earth Camp Teachers' Professional Development Workshop. Tucson, AZ.
- SHUTTLE (Art-Environment Collaborative Event). Tucson, AZ.
- Pima Association of Governments, Air Quality Forum. Tucson, AZ.
- Arizona Senior Academy. Vail, AZ.

July 2013

- San Pedro Riparian NCA Educational Forum. Sierra Vista, AZ.
- Drinking Liberally. Tucson, AZ.

August 2013:

- Access Tucson Television Show. Tucson, AZ.

September 2013:

- Pima Association of Governments, Environmental Planning Advisory Committee. Tucson, AZ.
- Biennial Conference of Science and Management on the Colorado Plateau. Flagstaff, AZ.
- Maricopa Bar Association. Phoenix, AZ.
- 26th Annual Arizona Hydrological Society Symposium. Tucson, AZ.
- Climate Ready Southwest: Ready or Hot? Tucson, AZ.
- Free Thought Arizona. Tucson, AZ.
- Southern Arizona Environmental Management Society. Tucson, AZ.

October 2013:

- Extension Sustainability Summit. Park City, UT.
- Climate Science and Solutions Professional Masters Program, Northern Arizona University. Flagstaff, AZ.
- Huachuca Audubon Society. Sierra Vista, AZ.
- Pima County Health Department, Strategic Warriors Against Transmission. Tucson, AZ.
- WESTCAS - Western Coalition of Arid States. Tucson, AZ.
- Sampler of International Learning in Retirement - Sun City Vistoso. Oro Valley, AZ.

November 2013:

- University Religious Council. Tucson, AZ.
- Regional Climate Summit for Municipal Leaders: Economic, Health, Water, and Transportation Impacts. Tucson, AZ.
- Tucson Electric Power and UNISOURCE Integrated Resources Plan Workshop. Tucson, AZ.

December 2013:

- Arizona-Sonora Desert Museum Docent Climate Training. Tucson, AZ.
- BLM Scenario Planning meeting, online orientation.

February 2014:

- Arizona Hydrological Society. Tucson, AZ.
- National Climate Change Preach-In. Sierra Vista, AZ.

March 2014:

- Confluence Center Show and Tell. Tucson, AZ.
- Tucson Festival of Books - Panel on Impacts of Climate Change & Panel on Southwest Climate Change. Tucson, AZ.

April 2014:

- Sabino Canyon Naturalists. Tucson, AZ.
- University of Arizona Solar Cats Green Talk. Tucson, AZ.
- Progressive Democrats of Arizona. Tucson, AZ.

National Climate Assessment

Lead CLIMAS Investigator: Gregg Garfin

Media coverage after the release of the National Climate Assessment:

Doug McIntyre Show - KABC Radio, Los Angeles, CA. May 8, 2014.

Banerjee, N. and K. Hennessey. 2014. Climate change assessment paints stark picture of potential damage. *Los Angeles Times.* May 6, 2014. http://www.latimes.com/nation/la-na-climate-change-assessment-20140505-story.html

Fleck, J. 2014. Report: NM to be hotter, drier. *Albuquerque Journal.* May 7, 2014. http://www.abqjournal.com/395501/news/nm-drier-hot-under-climate-change.html

Loomis, B. 2014. Worse Drought, wildfires forecast for the Southwest. *The Republic.* May 6, 2014. http://www.azcentral.com/story/weather/2014/05/07/worse-drought-wildfires-forecast-southwest/8796155/

Davis, T. 2014. Report: Southwest faces increased threat from drought, wildfires and heat. *Arizona Daily Star*. May 6, 2014. http://azstarnet.com/news/science/report-southwest-faces-increased-threat-from-drought-wildfires-and-heat/article_4314256a-d540-11e3-87b3-001a4bcf887a.html

Davis, T. 2014. Climate change hitting home, says White House report led by UA. *Arizona Daily Star*. May 7, 2014. http://azstarnet.com/news/local/education/college/climate-change-hitting-home-says-white-house-report-led-by/article_9b4e7d25-338b-5ee5-ab54-4f705bca5d20.html

The Story Group. 2014. *National Climate Assessment: Southwest Chapter Video*. http://vimeo.com/92687378

Sectoral Impacts of Drought and Climate Change

Lead CLIMAS Investigator: George Frisvold

1) Presentation to the Arizona House of Representatives, Committee on Agriculture and Water. *The Contribution of Agriculture to the Yuma Economy*. February 2014, Yuma, AZ.

   While agricultural-urban or agricultural-environmental water transfers have been identified as a key means to adapt to drought and climate change, there is concern in rural communities about the economic impacts of such "water exports". This presentation first discussed how to measure agriculture's contribution to a local economy. It then considered economic impacts of reduced water supplies to agriculture. This was an invited presentation by state, county, and city officials and business leaders, and has resulted in requests for further information and analysis (Agri-Business Council of Arizona, Arizona Farm Bureau, Office of Governor Jan Brewer, AZ).

2) Three presentations on the Drought, Crop Insurance, and the Farm Bill sponsored by Wells Fargo Bank. January 2014, Willcox, Casa Grande, and Yuma, AZ.

   Presentations were invited as part of an annual series of presentations that Wells Fargo Bank organizes for agricultural producers. There was special interest among producers on the effects of drought and on the structure of the new Farm Bill, which shifts most farm-income support programs to different types of insurance programs. This represents a significant policy change and producers were interested in hearing how the new insurance programs might affect them.

International Perspectives on Adaptation

Lead CLIMAS Investigator: Jonathan Overpeck

A series of international climate outreach talks in Australia, June 2013:

- *Changing climate and weather patterns in North America and SE Australia*. LaTrobe University. Melbourne, Victoria.
- *Assessing future megadrought risk*. University of Adelaide. Adelaide, South Australia.
- *Assessing future megadrought risk.* University of New South Wales. Sydney, New South Wales.
- *International perspectives on adaptation action: a view from the United States*. 2013 Adaptation Conference. National Climate Change Adaptation Research Facility. Sydney, New South Wales.
- *Development of a Roadmap for Enhanced Drought Monitoring and Prediction Services for Australia*. Australian Bureau of Meteorology Workshop. Melbourne, Victoria.

Selected Applications of CLIMAS Work 2013-2014

Climate and Weather Services for Disaster Management: A FEMA, NWS, and CLIMAS Collaboration

Lead CLIMAS Investigator: Michael Crimmins

A co-designed (FEMA, CLIMAS, NWS) custom climate information system for FEMA led to the development of a 'dashboard' of flood risk information including the creation of flood impact and precipitation climatologies. This experimental dashboard (developed by CLIMAS) is to be handed off to the Western Region Headquarters of the National Weather Service. If successful, this process will demonstrate a rare case of transitioning an experimental product to an operational product.

Planning for Drought in the Warming and Drying Southwest: Developing a Suite of Drought Indicators to Support Tribal Decision Making in the Four Corners

Lead CLIMAS Investigator: Daniel Ferguson

With the Hopi Department of Natural Resources (HDNR), this research team co-developed an experimental quarterly Hopi Drought Summary report. This product synthesizes various data sources that reflect ongoing drought status on Hopi lands. The first issue was released in early April 2014. The drought summary was explicitly designed to: a) provide the HDNR with a status update on drought conditions, and b) demonstrate to HDNR technicians how the data they collect may be utilized. In the spring of 2014, the director of the Hopi Department of Natural Resources credited this CLIMAS research team (via email) with helping refine and improve HDNR drought status monitoring.

Air Quality and Climate

Lead CLIMAS Investigator: David DuBois

Dust sources have become an important topic of discussion for land managers, weather forecasters, the health community, transportation planners, and members of the public. Members of this research team are trained to find dust source areas from satellite images and have created a database of these images over time. The visuals generated from the satellite imagery are eye-catching and make it easy to talk with stakeholders about the underlying causes of dust such as desertification, extreme events, and climate change. The team has printed several large maps and given them to stakeholders as wall posters. Several stakeholder groups have also used information about dust source locations for their own purposes. For example, the New Mexico Environment Department used dust source locations in their "Exceptional Events" reports that they submit to U.S. Environmental Protection Agency.

Measuring Success – Metrics and Indicators

CLIMAS is currently collecting data for evaluation in the following three themes:

1) Outreach
2) Graduate and Undergraduate Training
3) Advancing Science Knowledge

Data collection methods and indicators for a fourth theme of our evaluation – Use-Inspired Science and Decision Support – are in development.

Current and planned data collection has been built on specific indicators for each of the evaluation themes. Selected indicators are outlined below:

Theme 1: Outreach

Question: How does CLIMAS outreach influence people's understandings of climate and climate impacts in the Southwest?

Goal	**Indicator**	**Method**
CLIMAS is trusted source of information	number and quality of requests for information	build database of all information requests, including their relation to any outreach activity
create more informed consumers of climate research	number and quality of requests for specific topics for talks and presentations	build database of all requests for talks, including who made the request and their prior contact with CLIMAS

Question: How does CLIMAS outreach foster collaborative interactions between researchers and practitioners?

Goal	**Indicator**	**Method**
create dialogue between researchers and practitioners	number and quality of interactions between researcher and practitioner	build a database of all interactions between researchers and stakeholders
build a network of researchers and practitioners	researcher involvement in collaborations	build a database to track relationships between outreach activities and collaborative interactions
generate new transdisciplinary projects	new projects spawned by outreach	track new project origins

Theme 2: Graduate and Undergraduate Training

Question: What impact does CLIMAS have on future generations of researchers and practitioners?

Goal	Indicator	Method
Increase the number of students who gain experience/knowledge in use-inspired science	Numbers of students enrolled in CESD, applying for Fellowship, attending CLIMAS talks, employed as GRAs.	track numbers of students who interact with CLIMAS. Sign in sheet at CLIMAS talks
Deepen students' understandings and interests in use-inspired science	Change in knowledge about use-inspired over time	Pre- & Post- Interviews and surveys with students in CESD class/program and C&S Fellows
New applications of use-inspired science	Climate & Society Fellowship Project deliverables are new applications of use-inspired science	Interviews and surveys with C&S Fellows
Increase scope of CLIMAS to new academic disciplines	Increase in number of departments involved with CLIMAS	Track # of students and their departments – C&S Fellows, CESD, CLIMAS talks
Increase number of alumni who later teach, research, or practice with a use-inspired approach	Number of alumni who do this	Structured online survey with CLIMAS alumni about their current professional/academic endeavors

Theme 3: Advancing Science Knowledge

Question: How and in what areas does CLIMAS advance scientific knowledge?

Goal	Indicator	Method
contribute to advancing knowledge	number of annual publications	track all publications produced by researchers
impact on multiple fields	where manuscripts are published	Same as above
impact on knowledge	citation rate in other publications	Same as above
directly deliver info to specific stakeholder	number of stakeholder-driven reports	track all grey literature and intended audience
directly deliver USEFUL info	reports used for some purpose by stakeholder	structured interview with intended user of info in report

Appendix A: CLIMAS Publications 2013-2014

Ault, T. J. Cole, J. Overpeck, G. Pederson, and D. Meko. 2013. Assessing the risk of persistent drought using climate model simulations and paleoclimate data. *Journal of Climate* (in press). http://dx.doi.org/10.1175/JCLI-D-12-00282.1

Bilal, M., J. Nichol, M. Bleiweiss, and D. DuBois. 2013. A Simplified high resolution MODIS Aerosol Retrieval Algorithm (SARA) for use over mixed surfaces. *Remote Sensing of Environment* 136: 135-145. doi: 10.1016/j.rse.2013.04.014

Bleiweiss, M. and D. DuBois. 2013. Dust Source Locations from Remote Sensing Report for the Windblown Dust Emission Inventory for the International Border Region of Southern New Mexico. Report for the NM Environment Department, Air Quality Bureau.

Brusca R., J. Wiens, W. Meyer, J. Eble, K. Franklin, J. Overpeck, and W. Moore. 2013. Dramatic Response to Climate Change in the Southwest: Robert Whittaker's 1963 Arizona Mountain Plant Transect Revisited. *Ecology and Evolution* 3(10): 3307-3319. doi: 10.1002/ece3.720

Büyüktahtakin, I., Z. Feng, A. Olsson, G. Frisvold, and F. Szidarovszky. 2014. Invasive Species Control Optimization as a Dynamic Spatial Process: An Application to Buffelgrass (*Pennisetum ciliare*) in Arizona. *Invasive Plant Science and Management* 7(1): 132-146.

Büyüktahtakın, İ., Z. Feng, G. Frisvold, and F. Szidarovszky. 2013. Invasive species control based on a cooperative game. *Applied Mathematics* 4(10B): 54-59.

Chalbot, M., I. Kavouras, and D. DuBois. 2013. Assessment of the contribution of wildfires on ozone concentrations in the central US-Mexico border region. *Journal of Aerosol and Air Quality Research* 13: 838-848. doi: 10.4209/aaqr.2012.08.0232

DuBois, D., I. Kavouras, and M. Chalbot. 2013. Correlation of Human Health Conditions with Air Quality in the Border Binational Region of Southwestern NM-NM Chihuahua-West Texas. Prepared for the Department of Health, Office of Border Health. http://nmborderair.nmsu.edu/past-studies-and-inventories/health-assessment/

DuBois, D., I. Kavouras, M. Chalbot, M. Bean, M. Bleiweiss, R. Fitzgerald, and S. Engle. 2013. Modeling of Air Quality for the Assessment of Land-based Sources of Air Quality Contaminants in the Binational Border Region of Southwestern New Mexico, Northwestern Chihuahua and West Texas. Prepared for the Department of Health, Office of Border Health.

DuBois, D., I. Kavouras, M. Chalbot, M. Lytle, E. Smith, R. Armenta, M. Bleiweiss, Y. Zhao, and S. Engle. 2013. Determination of Actual and/or Most Probable Causes and Sources of Air Quality Contamination in the Border Region of Southwestern New Mexico-Northwestern Chihuahua-West Texas. Prepared for the Department of Health, Office of Border Health.

DuBois, D., I. Kavouras, M. Chalbot, M. Lytle, E. Smith, R. Armenta, M. Bleiweiss, Y. Zhao, and S. Engle. 2013. Descriptive Recommendations for Reducing Air Quality Contamination Specific to Causes, Sources, and Locations using BACT and BMPs. Prepared for the Department of Health, Office of Border Health.

DuBois, D., S. Sanogo, M. Bleiweiss, and M. Bean. 2013. Pollen Measures and Dispersion Studies. Prepared for the Department of Health, Office of Border Health. http://nmborderair.nmsu.edu/past-studies-and-inventories/pollen-measures-and-dispersion-studies/

DuBois, D. and Y. Zhao. 2013. Measurements of Wind Erosion using the PI-SWERL for the Windblown Dust Emission Inventory for the International Border Region of Southern New Mexico. Report for the NM Environment Department, Air Quality Bureau.

Frisvold, G. 2014. Effects of Climate Change Legislation on US Cotton Producers. In *2014 Proceedings of the Beltwide Cotton Conferences.* January 6-8, 2014, New Orleans, LA. Memphis, TN: National Cotton Council.

Frisvold, G., and K. Konyar. 2013. Climate Change Mitigation Policies: Implications for Agriculture and Water Resources. *Journal of Contemporary Water Research & Education* 151(1): 27-42.

Frisvold, G., L. Jackson, J. Pritchett, J. Ritten, and M. Svoboda. 2013. Agriculture and Ranching. In *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment.* Eds. Garfin et al. Washington, DC: Island Press, p. 218-239.

Frisvold, G. and G. Jin. 2013. Effects of weather extremes on cotton acreage abandonment and insurance indemnities. *Proceedings of the Beltwide Cotton Conferences*. Memphis, TN: National Cotton Council.

Frisvold, G. and T. Marquez. 2013. Water Requirements for Large-Scale Solar Energy Projects in the West. *Journal of Contemporary Water Research & Education* 151(1): 106-116.

Ferguson, D., R. Thomas, Z. Guido, L. Ethen, C. Zucker, G. Chorover, and R. Johnson. 2014. Planning for Change in Southern Arizona: A report from the Southern Arizona Regional Climate Summit for Municipal Leaders. Tucson: Climate Assessment for the Southwest. www.climas.arizona.edu/sites/default/files/pdfplanning-change-2014.pdf

Flores-Márgez, J., J. Hernández-Escamilla, M. Delgado-Ríos, A. Granados Olivas, and D. DuBois. 2014. Land-based Sources of Air Quality Contaminants in the Binational Border Region of Southwestern New Mexico, Northwestern Chihuahua, and West Texas. Submitted to the Border Environment Cooperation Commission.

Garfin, G. 2013. Assessment of Climate change in the Southwest United States: Key Findings. *5th Annual Science on the Sonoita Plain Symposium*. June 8, 2013. Elgin, AZ: Cienegas Watershed Partnership, p. 5-7.

Garfin, G., H. Chang, and M. Switanek. 2014. Chapter 3. Climate and Hydrology of the Upper Gila River Basin. In *Gila River-Arizona Water Settlement Act Ecological Flows Report.* Eds. D. Gori and M. Schumann. Santa Fe, NM: The Nature Conservancy in New Mexico.

Garfin, G., G. Franco, H. Blanco, A. Comrie, P. Gonzalez, T. Piechota, R. Smyth, and R. Waskom. 2014. Ch. 20: Southwest. Climate Change Impacts in the United States. *The Third National Climate Assessment.* Eds. J. Melillo, T. Richmond, and G. Yohe. U.S. Global Change Research Program, 462-486. doi:10.7930/J08G8HMN.

Garfin, G., G. Hakanson, S. LeRoy, and C. Greene. 2013. Fact Sheets for Chapters 3-20. In *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment*. Eds. G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy. Washington, DC: Island Press. http://www.swcarr.arizona.edu/key-findings

Garfin, G. and A. Jardine. 2013. Overview. In *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment*. Eds. G. Garfin, A.

Jardine, R. Merideth, M. Black, and S. LeRoy. Washington, DC: Island Press, p. 21-36. http://swcarr.arizona.edu/chapter/2

Hernandez Escamilla, J., J. Flores Margez, M. Ramirez, N. Mendoza, M. Rios, M. Shukla, and D. DuBois. 2013. Artículo de investigación, material particulado dispersado al aire en areas sin asfalto en Ciudad Juarez. *Ciencia en la frontera: revista de ciencia y technologia de la UACJ*, Vol. XI, Ciudad Juárez, Chihuahua: UACJ, p. 9-14.

Kavouras, I., M. Chalbot, and D. DuBois. 2013. Receptor-Based Dust Source Analysis for the Windblown Dust Emission Inventory for the International Border Region of Southern New Mexico. Report for the NM Environment Department, Air Quality Bureau.

Marquez, T. 2013. *Factors Influencing the Deployment of Utility Scale Solar Power in the United States*. M.S. Thesis. Department of Agricultural and Resource Economics, University of Arizona.

Norman, L., M. Villarreal, R. Niraula, T. Meixner, G. Frisvold, and W. Labiosa. 2013. Framing Scenarios of Binational Water Policy with a Tool to Visualize, Quantify and Valuate Changes in Ecosystem Services. Water 5(3): 852-874.

Overpeck, J. 2014. The challenge of biodiversity adaptation under climate change. In *Applied Studies in Climate Adaptation.* Eds. J. Palutikof, S. Boulter, J. Barnett, and D. Rissik. Wiley: Oxford (In press).

Overpeck, J., G. Garfin, A. Jardine, D. Busch, D. Cayan, M. Dettinger, E. Fleishman, A. Gershunov, G. MacDonald, K. Redmond, W. Travis and B. Udall. 2013. Summary for Decision Makers. In *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment*. Eds. G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy. Washington, DC: Island Press, p. 1-20. http://swcarr.arizona.edu/chapter/one

Pfeiffer, G. 2013. *Diffusion of Solar Technology in Agriculture*. M.S. Thesis. Department of Agricultural and Resource Economics, University of Arizona.

Richards, H. 2013. *The Footprint of Growth: A Multi-faceted Environmental Kuznets Curve Analysis of CO2 Emissions in the U.S.* M.S. Thesis. Department of Agricultural and Resource Economics, University of Arizona.

Rodopoulou, S., M. Chalbot, E. Samoli, D. DuBois, B. San Filippo, and I. Kavouras. 2014. Air pollution and hospital emergency room and admissions for cardiovascular and respiratory diseases in Dona Ana County, New Mexico. *Environmental Research* 129: 39-46. doi: 10.1016/j.envres.2013.12.006

Rogers, J., K. Averyt, S. Clemmer, M. Davis, F. Flores-Lopez, P. Frumhoff, D. Kenney, J. Macknick, N. Madden, J. Meldrum, J. Overpeck, S. Sattler, E. Spanger-Siegfried, and D. Yates. 2013. *Water-smart power: Strengthening the U.S. electricity system in a warming world.* Cambridge, MA: Union of Concerned Scientists.

Smith, E. 2014. *Dust Abatement in the Mesilla Valley*. M.S. Thesis. Department of Plant and Environmental Sciences, New Mexico State University. http://nmborderair.nmsu.edu/past-studies-and-inventories/dust-control-study/

Vano, J., B. Udall, D. Cayan, J. Overpeck, L. Brekke, T. Das, H. Hartmann, H. Hidalgo, M. Hoerling, G. McCabe, K. Morino, R. Webb, K. Werner, and D. Lettenmaier. 2013. Understanding Uncertainties in Future Colorado River Streamflow. *Bulletin of the American Meteorology Society* 95: 59–78. http://dx.doi.org/10.1175/BAMS-D-12-00228.1

Weiss, J. 2014. *Potential Changes in Future Regional Climate and Related Impacts: A brief report for the Central New Mexico Climate Change Scenario Planning Project*.

Werner, K., K. Averyt, and G. Owen. 2013. River Forecast Application for Water Management: Oil and Water? *Weather, Climate, and Society* 5(3): 244-253.

Wilder, M., G. Garfin, P. Ganster, H. Eakin, P. Romero-Lankao, F. Lara-Valencia, A. Cortez-Lara, S. Mumme, C. Neri, and F. Muñoz-Arriola. 2013. Climate Change and U.S.-Mexico Border Communities. In *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment*. Eds. G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy. Washington, DC: Island Press, p. 340-384. http://swcarr.arizona.edu/chapter/16